Measuring spectrum pollution at VHF

Introduction

In his lecture on 'Electrical Units of Measurement' given to the Institution of Civil Engineers on 3 May 1883, Lord Kelvin, one of the fathers of modern engineering and science, stated

"...when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of science".

This article is based on a talk [1] given by Alwyn Seeds, G8DOH at the 2017 RSGB Convention and aims to present simple methods to measure the received noise level at VHF/UHF. The received noise level at your location is critically important because it determines the weakest signals that can be received successfully. In many cases it defines the overall performance of your VHF station, and no amount of technology or expensive rigs and antennas can, in the end, overcome its influence. The article also covers an introduction to noise units and measurement, and describes some of the noise sources at VHF/UHF, including radiated noise from amateur transmitters.

Units of power

In SI [2] units, power is measured in watts (W) and it is often useful to measure the ratio between two powers, P/Pr, such as the loss or gain of a circuit; this is a dimensionless quantity and these ratios can sometimes be large – eg the path loss between two antennas. This ratio is usually expressed in decibels (dB), where power ratio (dB) = $10 \log_{10}(P/Pr)$. This should not be confused with dBW or dBm, which are used to specify *absolute* powers, expressed as the ratio of a power measured in milliwatts (mW) or watts to either 1mW or 1W respectively:

Power P in dBm = $10 \log_{10}(P/(1mW))$ and

Power P in dBW = $10 \log_{10}(P/(1W))$

Noise

Noise is defined as a random fluctuation in a quantity. In the field of amateur radio, we experience this noise as a background to the signals we hear at the output of our receiver. More specifically, white noise is noise that has uniform power with frequency. It has measurement units of power, ie watts (W). If we want to define the amount of noise in a given bandwidth, we define 'noise spectral density' (NSD). This is the noise power per unit bandwidth and has units of power divided by bandwidth, or watts per hertz.

Thermal noise

Thermal noise is fundamental to all systems above a temperature of absolute zero (0K) and is the noise created by the thermally induced random motion of charge carriers. The thermal noise power of a resistor P_n is proportional to the temperature of the system T and the measurement bandwidth B. It is equal to k times T times B (kTB), where k is Boltzmann's constant, 1.38×10^{-23}J per K. T is the temperature in kelvin and B the measurement bandwidth in Hz.

As an example of this thermal noise, in **Figure 1** a resistor at *standard noise temperature*, T_o, 290K (16.85°C) generates a noise power in 1Hz bandwidth of

$P_n = kTB$

$= 1.38 \times 10^{-23} \times 290 \times 1$

$= 4.00 \times 10^{-21}$W

$= -174$dBm/Hz

Received noise measurement

To measure received noise from a receiver with gain G and added noise power N_a, we can substitute the antenna with a 50Ω resistor as a noise source. **Figure 2** shows the noise produced by each. Power out with the load connected is equal to $P_{outL} = GkTB + N_a$

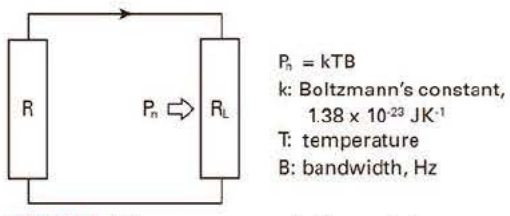

FIGURE 1: Noise power generated in a resistor.

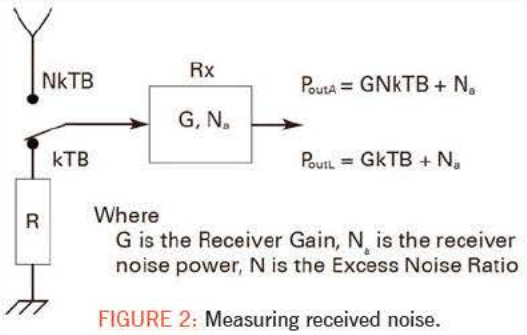

FIGURE 2: Measuring received noise.

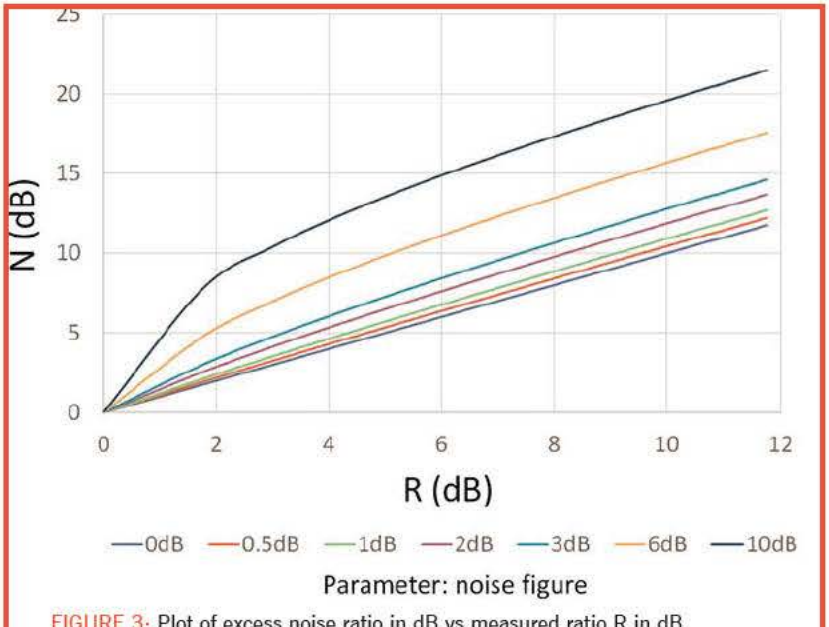

FIGURE 3: Plot of excess noise ratio in dB vs measured ratio R in dB.

With the antenna connected it is

$P_{outA} = GNkTB + N_a$

where G is the receiver gain, N_a is the receiver noise power, N is the excess noise ratio, the ratio of the noise received by the antenna to the noise received from the 50Ω resistor. Rearranging, we get the noise power ratio R due to the antenna as

$R = P_{outA}/P_{outL}$

$= (GNkTB+N_a)/(GkTB+N_a)$

or

$N = (P_{outA}/P_{outL})[1+N_a/(GkTB)]-N_a/GkTB$

For a receiver with negligible internally generated noise, $N = R = P_{outA}/P_{outL}$, so that we can determine the excess noise ratio simply by comparing the output noise of the receiver when connected to the antenna to that when connected to the 50Ω load.

For receivers with non-negligible internally generated noise the excess noise ratio is greater than the noise power ratio measured at the receiver output and a correction factor is required, depending on the receiver noise factor.

N_a can be expressed in terms of the receiver noise factor *F*:

$N_a = G\,[F-1]kT_oB$

where *F* is the noise factor and T_o is standard noise temperature, 290K. Thus, the excess noise ratio, N, in terms of the receiver noise factor is

$N = F(P_{outA}/P_{outL})-F+1$

Note that the familiar 'noise figure' NF is simply the noise factor expressed in dB: $NF(dB) = 10\log_{10}(F)$.

If we take the example of a receiver with a measured noise figure of 3dB ($F = 2$),

$N = F(P_{outA}/P_{outL})-F+1$

$= 2(P_{outA}/P_{outL})-2+1$

$= 2(P_{outA}/P_{outL})-1$

If we plot the excess noise ratio in dB vs the measured ratio $R = (P_{outA}/P_{outL})$, between the noise with the antenna and the noise with the 50Ω load in dB with the receiver noise figure, also in dB, as a parameter, we get **Figure 3**.

The excess noise ratio, N, is found from the intersection between the measured ratio, R and the curve for the noise figure of the receiver.

Noise Factor measurement

The noise factor of the receiver can be found from equipment reviews or can be measured with a calibrated noise source, as shown in **Figure 4**.

The baseline noise power and excess noise ratio can be measured using a calibrated receiver. Computer software such as that used for many digital modes including the WSJT suite (using the spectrum/waterfall window) allows direct measurement of received power changes. Alternatively, a receiver with AGC switched off and a multimeter capable of measuring AC voltages at the receiver audio output can be used, as shown in **Figure 5**.

We need to test at several different audio levels to ensure that noise levels are within the linear range of the detector. The excess noise ratio is then found from

$N = F\,(V_{outA}/V_{outL})^2 - F + 1$

where V_{outA} and V_{outL} are the AC voltages measured at the audio output with the antenna and the load connected respectively.

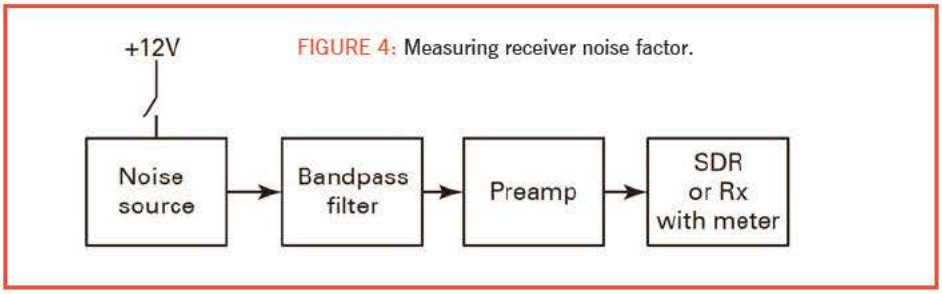

FIGURE 4: Measuring receiver noise factor.

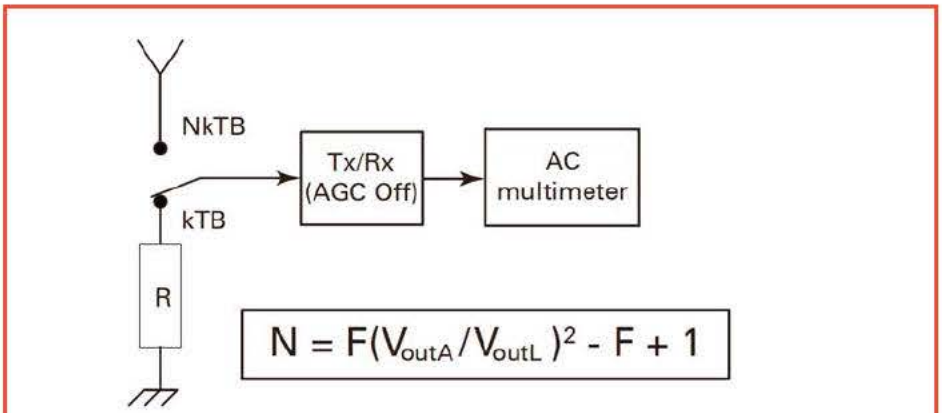

FIGURE 5: Low cost noise measurement system.

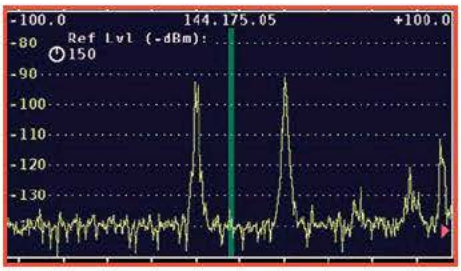

FIGURE 6: Spectrum with noisy transmitter off.

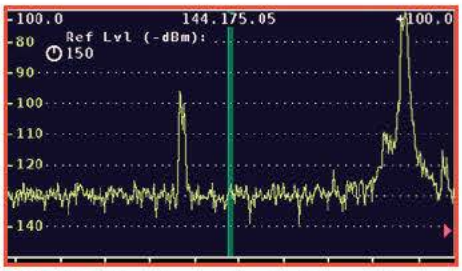

FIGURE 7: Spectrum with noisy transmitter on.

Received noise

At a perfect quiet site with no man-made noise and with an antenna pointed at the horizon, allowing for the fact that at least half of an antenna's main lobe is looking at the ground and the other half looking at galactic noise, the lowest excess noise ratios we would expect to measure would be those shown in **Table 1**.

In practice, noise floors can be up to 10dB above these values and higher still in urban areas. Receivers should have internally generated noise less than these levels and transmitters within the band should not raise them.

Some real world measurements of band noise in rural Oxfordshire (IO92fa) were made by G8DOH and are shown in **Table 2**. These should be compared with measurements shown in **Table 3**, made in central London, IO91vl, where the received noise levels were much higher.

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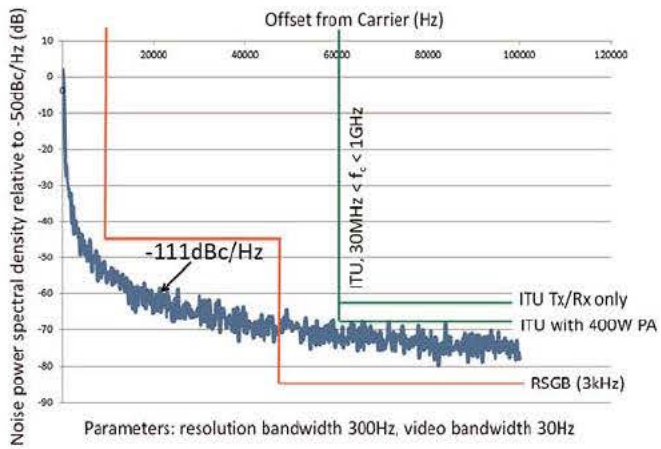
Offset from Carrier (Hz)
Noise power spectral density relative to -50dBc/Hz (dB)
-111dBc/Hz
ITU, 30MHz < fc < 1GHz
ITU Tx/Rx only
ITU with 400W PA
RSGB (3kHz)
Parameters: resolution bandwidth 300Hz, video bandwidth 30Hz

FIGURE 8: A 'noisy' 144MHz system – IC-910H + PA.

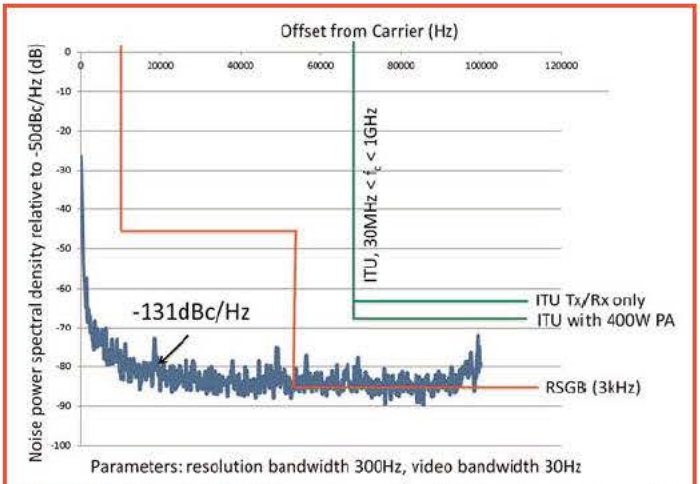
Offset from Carrier (Hz)
Noise power spectral density relative to -50dBc/Hz (dB)
-131dBc/Hz
ITU, 30MHz < fc < 1GHz
ITU Tx/Rx only
ITU with 400W PA
RSGB (3kHz)
Parameters: resolution bandwidth 300Hz, video bandwidth 30Hz

FIGURE 9: A 'quiet' 144MHz system – Elecraft K3 + transverter + PA.

External noise sources at VHF/UHF

Many items of electrical equipment can generate unwanted noise at VHF; these include switch mode power supplies for lighting, photovoltaic converters for domestic and industrial solar panels, IT equipment, Ethernet, including Power over Ethernet (POE) and digital subscriber line (DSL) wiring.

Transmitter noise

Radiated noise from a transmitter, on either side of the main carrier, is becoming a more important issue with modern, low voltage rail transceivers and software defined radios. As a general statement it can be said that the performance of commercial transceivers is getting worse, not better, as we add usability features at the expense of noise performance.

Figure 6 shows a spectrum analyser display of part of the 144MHz band during the 2016 144MHz Trophy contest, recorded at IO92fa when a station with high transmitter noise is not transmitting. Resolution bandwidth is 444Hz and the noise floor is -167dBm/Hz. Figure 7 shows the same plot but this time the noisy station is transmitting. Although the station is 129km away and only producing a received power of -55dBm, the noise floor at IO92fa is raised by 10dB to -157dBm/Hz, masking weak signals across the band.

Let's put this in perspective. For the victim of this excess transmitter noise to continue hearing a 25W DX station at the same signal to noise ratio as before, the DX station would need to turn his/her power up to 250W! Some rigs are much worse than others and there's a good set of measurements that compare various different amateur radio rigs at SM5BSZ's website [3].

If we look at the comparison between a 'noisy' and a 'quiet' contest system as shown in Figure 8 and Figure 9 we can clearly see the extent of the problem. The 'quiet' system is some 20dB better in carrier to noise ratio than the 'bad' one.

TABLE 1: Ideal excess noise ratios.

Band	Noise temperature	Noise spectral density	ENR (minimum galactic)
50MHz	2000K	-165dBm/Hz;	N = 9dB
70MHz	800K	-170dBm/Hz;	N = 4dB
144MHz	300K	-173dBm/Hz	N = 1dB
432MHz	180K	-175dBm/Hz	N = -1dB
1296MHz	150K	-176dBm/Hz	N = -2dB

TABLE 2: Excess noise ratios (ENR) measured in rural Oxfordshire.

Band	Noise figure (dB)	ENR (min galactic) (dB)	ENR (measured) (dB)
50MHz	12	9	14
70MHz	6	4	4
144MHz	3	1	3
432MHz	5	-1	1

TABLE 3: Excess noise ratios (ENR) measured in central London.

Band	Noise figure (dB)	ENR (min galactic) (dB)	ENR (measured) (dB)
50MHz	3	9	18
144MHz	3	1	17
432MHz	3	-1	5

Conclusions

To be able to hear terrestrial DX at VHF/UHF, very high dynamic range receivers are required, together with a low level of received noise. Received noise can be measured with simple equipment to a useful level of accuracy. In-band noise from poor quality transmitters is an increasing problem and is something that is within our control. It is recommended that you do not purchase any transceiver that has radiated noise of more than -130dBc/Hz at 50kHz offset from the carrier. Look for better performance. Older models are actually often better than current ones – and are frequently cheaper, too!

You can measure the received noise in your area using the simple methods described here, so that quantitative information on radio noise is available to influence policy. We will soon give details on how you can submit your results online. Doing so will help the RSGB in its dealings with the licencing authorities on noise and interference topics, for the benefit of all amateurs.

References

[1] see www.rsgb.org/videos and follow the links to Convention lectures 2017
[2] International system of units, https://en.wikipedia.org/wiki/International_System_of_Units
[3] www.sm5bsz.com/dynrange/rig_compare.htm